A REVIEW OF CHEMICAL CONTROL METHODS FOR BLACKFLY LARVAE (DIPTERA: SIMULIIDAE)

MARY M. CHANCE
Department of Entomology
University of Alberta
Edmonton, Alberta

Quaestiones entomologicae
6 : 287-292 1970

Chemical methods of controlling blackflies are reviewed. DDT has been the most satisfactory material in terms of selectivity and economy. Methods of application of DDT, its effect on blackflies and other aquatic invertebrates, and research on safer alternative compounds to DDT including methoxychlor and Abate® are discussed.

Methods of control of blackfly larvae have been mainly chemical. Many chemicals have been tested for effectiveness as simuliid larvicides (Cope et al., 1949; Kindler and Regan, 1949; Gjullin, Cope, Quisenberry and DuChanois, 1949; Hocking et al., 1949; Wanson et al., 1949; Wanson et al., 1950; Hocking, 1950, 1953; Travis et al., 1951; Lea and Dalmat, 1954, 1955a, 1955b; Taufflieb, 1955; Noel-Buxton, 1956; Muirhead-Thompson, 1957; Davies et al., 1962; Fredeen, 1962; Jamnback and Eabry, 1962; Travis and Wilton, 1965; Guttman et al., 1966; Frempong-Boadu, 1966; Jamnback and Frempong-Boadu, 1966; Travis and Guttman, 1966; Kuzoe and Hagan, 1967; Raybould, 1967; Swabey et al., 1967; Burdick et al., 1968; Jamnback and Means, 1968; Travis and Schuchman, 1968).

Until recently DDT (2,2-bis[*p*-chlorophenyl]-1,1,1-trichloroethane) was considered the most satisfactory because of its specificity, cost and ease of application and it has been used almost exclusively since the earliest control programs. The first control program with DDT was by Fairchild and Barreda (1945) in South America. Garnham and McMahon (1947) eradicated *Simulium neavei* Roubaud in Kenya where it was the vector for onchocerciasis. Wanson et al. (1949) applied it aerially to combat *Simulium damnosum* Theobald at Leopoldville in the Congo. These and other control programs in Africa have been reviewed by McMahon et al. (1958), Brown (1962), and J. B. Davies et al. (1962) who reviewed control programs in Africa as well as South America. Jamnback and Collins (1955) comprehensively reviewed control programs, in particular those carried out in New York State, U. S. A.

CONTROL WITH DDT

Research on control has been concerned mainly with formulation of DDT, and its mode and time of application. DDT has been applied in oil solutions (Hoffmann and Merkel, 1948; Hocking et al., 1949; Barnley, 1958; Crosskey, 1959; Davies et al., 1962; Fredeen, 1962), as emulsions, emulsifiable concentrates (= solutions in xylene or toluene and Triton X-100), and wettable powders (Tiller and Cory, 1947; Hocking et al., 1949; Fredeen, Arnason and Berck, 1953; Fredeen, Arnason, Berck and Rempel, 1953; Lea and Dalmat, 1955b; Noel-Buxton, 1956; Brown, 1962; Travis and Wilton, 1965; Kershaw et al., 1968), in suspension (Travis and Wilton, 1965), as miscible liquids (McMahon et al., 1958; Davies et al., 1962), as solutions in acetone (Cope et al., 1949; Gjullin, Cope, Quisenberry and DuChanois, 1949; Prevost, 1949), in cakes of plaster-impregnated sawdust bags, impregnated plaster blocks, and impregnated muslin sand bags (Fairchild and Barreda, 1945; Prevost, 1949; Jamnback, 1952; Hocking and Richards, 1952; Hocking, 1953; Jamnback and Collins, 1955). The emulsified form is preferred over other formulations, being one of the most effective formulations in the field, and one of the easiest to apply by hand (Brown, 1962; Jamnback and Frempong-Boadu, 1966). Spectacular results have been achieved using DDT adsorbed onto solids which form a suspension when put into streams (Fredeen, Arnason and

Berck, 1953; Fredeen, Arnason, Berck and Rempel, 1953; Noel-Buxton, 1956).

Fredeen (1962) has shown that formulations including oil are more effective when added to turbid waters than when added to clear waters. The DDT probably adsorbs onto the suspended solids and is ingested by the blackfly larvae.

In large scale programs where the terrain is rugged, aerial application has been very successful, not only against larvae but also, at higher dosages, against the adults. Aerially applied formulations are more concentrated but the exposure time is shorter (Hocking, 1953; Jamnback and Collins, 1955). Oil solutions are best (Hocking, 1950; Hocking and Richards, 1952) and are generally applied at a rate of 0.1 lb.–0.3 lb. DDT/swath-acre (Gjullin, Sleeper and Husman, 1949; Travis et al., 1951; Brown, 1952), although as much as 1 lb./swath-acre has been applied (Goulding and Deonier, 1950). Application of larvicides should be made immediately after hatching and before the beginning of pupation. Water level and rate of flow influence the dosage required (Jamnback, 1952; Jamnback and Collins, 1955; Noel-Buxton, 1956; McMahon et al., 1958; Crosskey, 1959; Davies et al., 1962; Kuzoe and Hagan, 1967).

The popularity of DDT as a blackfly larvicide is due to its greater toxicity to blackflies than to some other members of the stream fauna, and to its greater safety for mammals. Larvae are killed at very low concentrations, 0.025–0.05 ppm. Under Canadian conditions a dosage of 0.1 ppm for 15 minutes is sufficient applied direct to the water; dosages as high as 0.5 ppm for 60 minutes are applied in other parts of the world.

Effects on other aquatic animals

Despite the selectivity of DDT for blackfly larvae, other members of the stream fauna are affected. Many of these animals are also susceptible to other candidate larvicides. The variation in amount of DDT applied in the studies referred to here is partially responsible for the differences in results. After application of DDT, up to 80% reductions have been recorded in populations of mayflies, stoneflies, and caddisflies (Arnason et. al., 1949; Corbet, 1958; Hynes, 1960; Hynes and Williams, 1962). Garnham and McMahon (1947) reported that many invertebrates and fish were destroyed. Hoffmann and Merkel (1948) reported reductions of 61% and 90% of the stream fauna for five miles downstream from application. Hoffmann and Drooz (1953) found 70% and 90% reductions in fish foods. Hoffmann and Surber (1948) reported reductions of 74% in insects, including caddisflies, mayflies, beetles, and flies. Some species of stoneflies, beetles, dobsonflies, alderflies, water mites, dragonflies, crustaceans, molluscs and worms were not affected. Gjullin, Cope, Quisenberry and DuChanois (1949) found 90% to 100% mortality of caddisflies. Hocking et al. (1949) recorded deaths in 37 families of stream-inhabiting organisms. McMahon et al. (1958) reported losses of large numbers of insects. However, certain species of mayflies, midges, and leeches appeared to be resistant. Hynes and Williams (1962) reported the elimination of species of ostracods, mayflies, beetles, and three families of flies. Jamnback and Eabry (1962) reported a reduction of mayflies and flies.

Populations of blackflies and mayflies reappeared in treated streams within a year (Garnham and McMahon, 1947; Hoffmann and Merkel, 1948; Hoffmann and Drooz, 1953; Brown, 1962; Davies et al., 1962) and were the most numerous members of the stream fauna after repopulation (Hoffmann and Merkel, 1948; Hynes and Williams, 1962). This increase in their numbers is attributed to the absence of predators and shows that applications of DDT can lead to outbreaks of blackflies (Davies, 1950).

In comparison, in a 10-year program carried out in New York State, DDT had little effect on some arthropods (Collins and Jamnback, 1958; Jamnback and Eabry, 1962). After years of use of DDT in the streams, the populations of mayflies and flies differed significantly between treated and untreated streams; but populations of beetles, dragonflies, stoneflies, dobsonflies, caddisflies, and crustaceans were the same. Overall productivity was also the same.

Although Garnham and McMahon (1947) reported deaths among fish, other workers found fish unharmed immediately after applications of DDT in the recommended dosages (Cope et al., 1949; Gjullin, Cope, Quisenberry and DuChanois, 1949; Hocking et al., 1949; Travis et al., 1951; Collins et al., 1952; Hoffmann and Drooz, 1953; Jamnback, 1955; Noel-Buxton, 1956; Corbet, 1958; Hoffmann, 1959; Brown, 1962). Fish kill occurs but only in atypical conditions (Browne, 1960; Brown, 1962; Kershaw et al., 1968) or when the flow of insecticide is impeded (Crosskey, 1959; Kuzoe and Hagan, 1967). Post and Garms (1966) report that small and young fish are more susceptible than large and full-grown fish. They suggest that fish mortality is due to the differential distribution of insecticide in the water. The species of fish they studied are more susceptible to long exposure of low concentration of DDT than to short exposure of high concentration of DDT. Hocking (1950), and Hocking and Hocking (1962) suggested that the long term effects on fish may be profound.

Mortality of aquatic invertebrates other than blackflies is greatly reduced when DDT adsorbed onto solids is used (Fredeen, Arnason, Berck and Rempel, 1953; Noel-Buxton, 1956; Kershaw et al., 1965; Kershaw et al., 1968). Cope et al. (1949) suggested that a solution of DDT in acetone provided a safety margin between blackflies and fish, mayflies, and caddisflies.

ALTERNATIVE COMPOUNDS TO DDT

With the discovery of its long term stability in nature and its accumulation through a food chain, DDT has become less popular in control programs. Furthermore there is evidence that the larvae of a species of blackfly are resistant to DDT (Suzuki et al., 1963). In the last few years investigations have centered on discovering a biodegradable substitute for DDT. However, few of the more promising candidate compounds are either as safe to handle or as economical as DDT.

Both Lindane (δ-1,2,3,4,5,6-hexachlorocyclohexane) and crude benzene hexachloride (BHC) had also been used in Africa (Wanson et al., 1949; Wanson et al., 1950; Taufflieb, 1955) but were far from successful, killing other fauna including fish and giving poor control of blackflies. BHC and chlorten (chlorinated *a*-pinene) have also been used to control blackflies with limited success in Russia (Petrishcheva and Saf'yanova, 1959).

Screening tests of many compounds have been carried out under the sponsorship of the World Health Organization (Jamnback and Frempong-Boadu, 1966) and other organizations. The most promising compounds so far discovered include Abate® (*O,O,O',O'*-tetramethyl *O,O'*-thio-*p*-phenylene phosphorothioate) (Travis and Guttman, 1966; Swabey et al., 1967; Jamnback and Means, 1968), carbaryl (*N*-methyl-1-napthyl carbamate) (Frempong-Boadu, 1966), diazinon (*O,O*-diethyl *O*-[2-isopropyl-4-methyl-6-pyrimidinyl] phosphorothioate) (Jamnback, 1962; Travis and Guttman, 1966; Swabey et al., 1967), Dursban® (*O,O*-diethyl *O*-[3,5,6-trichloro-2-pyridal] phosphorothioate) (Travis and Schuchman, 1968), fenthion (*O,O*-dimethyl *O*-4-[methylmercapto]-3-methylphenyl phosphorothioate) (Jamnback, 1962; Frempong-Boadu, 1966; Raybould, 1967; Swabey et al., 1967), heptachlor (1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-endomethanoindene) (Fredeen, 1962), Korlan® (24% ronnel) and ronnel (*O,O*-dimethyl *O*-2,4,5-trichlorophenyl phosphorothioate) (Travis and Schuchman, 1968) and methoxychlor (2,2-bis[*p*-methoxyphenyl]-1,1,1-trichloroethane) (Frempong-Boadu, 1966; Travis and Guttman, 1966; Burdick et al., 1968; Jamnback and Means, 1968). Methoxychlor is safer than DDT and is an acceptable substitute as a blackfly larvicide (Burdick et al., 1968; Travis and Schuchman, 1968). More work is required before the efficiency and safety of the other compounds as larvicides are fully known.

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